BMP Effectiveness Monitoring

Acknowledgements

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Overview

- What to measure – Parameters of concern
- Identify the problem
- Monitoring Design - How to monitor the effectiveness of a BMP
- Sampling Frequency – How many samples do I need to collect?
- Sampling Duration – How long do I need to collect samples?

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Parameters of Concern

- Nutrients
- Metals
- Sediment
- Pesticides/Herbicides
- Most likely a concern because of the presence of these parameters at concentrations above a water quality standard

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Nutrients

- Total nitrogen is the sum of total kjeldahl nitrogen (TKN) plus nitrate (NO_3^-) and nitrite (NO_2^-)
- TKN is the sum of organic nitrogen and ammonia (NH_3) - in an unfiltered sample represents these forms of nitrogen that are present in solid and dissolved phases, in a filtered sample represents these forms of nitrogen in the dissolved phase
- Organic nitrogen is nitrogen incorporated in organic molecules – proteins (amino acids)

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Nutrients

- Orthophosphate (PO_4^{3-}) – primary inorganic form of phosphorus in the aqueous phase
- Dissolved phosphorus – the sum of phosphorus incorporated in organic molecules and orthophosphate in the aqueous phase
- Total Phosphorus - the sum of phosphorus incorporated in organic molecules in solid and aqueous phases and orthophosphate

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Forms of Nitrogen

Variable	Details
Total N	All forms of N, organic and inorganic. It is the sum of TKN + NO_3 + NO_2
TKN	Organic N plus ammonia N. Does not include nitrite and nitrate.
Organic N	TKN minus ammonia N.
NO_3	Inorganic nitrate.
NO_2+NO_3	Inorganic nitrite plus nitrate.

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Forms of Phosphorus

Variable	Details
Total P	All P forms converted to dissolved ortho-PO_4 and measured.
Ortho-PO_4	Primary inorganic form of phosphorus
Dissolved organic phosphorus	Dissolved P minus Ortho-P
Total organic phosphorus	Total P minus Dissolved P

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Metals

- Total – metal in an unfiltered sample, represents the metal present in solid and dissolved phases. EPA drinking water regulations are based on total concentrations.
- Dissolved – metal in a filtered sample, represents metal in the aqueous phase only. Biological availability to aquatic organisms is determined by metal in the aqueous phase.

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Sediment-Related Terms

- SSC – Suspended Sediment Concentration (mg/L)
- TSS – Total Suspended Solids (mg/L)
- TDS – Total Dissolved Solids
- Turbidity – Nephelometric Turbidity Units
- Gray, J.R., Glysson, G.D., Turcios, L.M., and Schwarz, G.E., 2000: Comparability of suspended-sediment concentration and total suspended solids data, U.S. Geological Survey Water Resources Investigations Report 00-4191, 14p.

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SSC, TSS, TDS

- SSC - Sediment from natural waters consisting of sand, silt, and clay derived from the weathering and erosion of rocks and soil.
- TSS – Derived for wastewater and includes organic material.
- TDS – Measure of total amount of dissolved material

Turbidity

- Measure of water clarity
- Caused by the presence of suspended and dissolved matter
- Includes inorganic particulates (sand, clay, and silt) and organic material such as plankton and organic acids (humic substances)

Pesticide/Herbicide

- Targeted compound will often breakdown into other compounds, may need to analyze these compounds as well.
- May need to consider sampling of stream/lake bed sediments and biota to fully understand fate and transport of pesticides/herbicides.

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Identify the Problem

- Reconnaissance/Synoptic Sampling
  - Identify pollutant(s)
  - Identify pollutant source(s)
  - Data collected using EPA 106 funding
  - Data collected from other sources – Federal, State, Local Agencies, Universities/Colloges/ Private Consulting Firms

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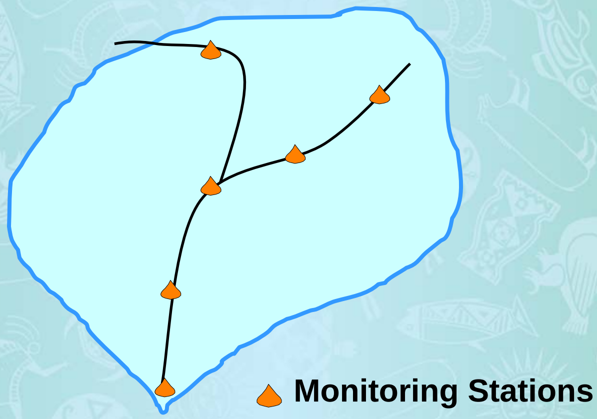
Reconnaissance/Synoptic



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Identify the Problem

- Sampling Locations
  - Mouths of tributaries, on main stem above and below tributaries, and at changes in land use or geology
- Data Analysis
  - Does parameter(s) of concern exceed the appropriate state, federal, or tribal water quality standard for the designated use of the stream or river.
  - Identify sources of high concentrations

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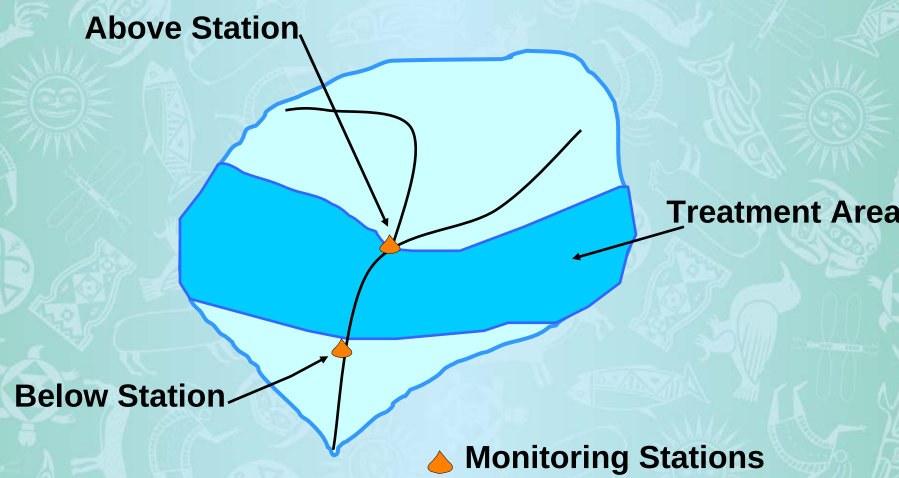
Above/Below Monitoring



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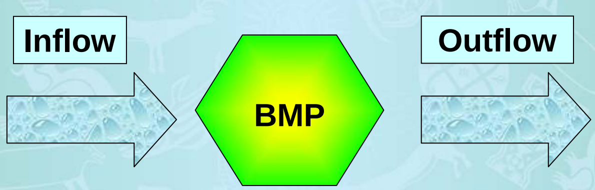
Input/Output



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Monitoring Design

- Same monitoring design for Above and Below and Input/Output
- Sampling needs to bracket the range of seasonal variability in weather, stream flows, and human activity over the course of a year
- Sample upstream and downstream sites as matched pairs – sample both sites at about the same time and as close in time as possible

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Monitoring Design

- If streamflow is measured can analyze loads as well as concentration
- Mass balance calculation - allows for a calculation of pollutant removal efficiency

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Hypothesis Test

- Compute differences in concentration between upstream and downstream site (D_i) for each sampling event.
- Null Hypothesis – Mean of $D_i = 0$
- Alternative Hypothesis – Mean of $Di \neq 0$
- Paired t-test if the differences follow a normal distribution
- Wilcoxon signed-rank test if the differences do not follow a normal distribution
- See Chapter 6 in Helsel, D.R. and Hirsch, R.M., 1992, Statistical Methods in Water Resources, Elsevier, New York, 522 p.

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Sampling Frequency

- **Appropriate sample frequency/size varies with the objectives of the monitoring project:**
  - Estimation of the mean
  - Detection of change

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Mean Estimation

- **Determine the sampling frequency necessary to obtain an estimate of the mean for a water quality variable with a certain amount of confidence**

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Mean Estimation

$$n = \frac{t^2 s^2}{d^2}$$

where:

n = the calculated sample size

t = Student's t at (n-1) degrees of freedom and a specified confidence level

s = estimate of the population standard deviation

d = acceptable difference of the estimate from the true mean

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Mean Estimation

- t value is taken from a table of Student's t at the desired confidence level (*p*), typically 0.05 or 0.10).
- Estimate of the population standard deviation is best obtained from baseline data from the monitored water body; if such data are lacking, an estimate from a comparable nearby system can be used.
- Acceptable difference from the true mean is expressed as a percent of the mean.

Calculation may be an iterative process as the value of t may change with the particular value of n chosen

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Mean Estimation - Example

Based on historical monitoring data from Ramirez Brook, how many samples are needed to be within 10 and 20 percent of the true annual mean TP concentration?

- Existing data tell us: Mean = 0.89 mg/L
  Std Dev.= 0.77 mg/L
  n = 165
- The difference (d) for 10% and 20% would be:
  d = 0.10 x 0.9 = 0.09 mg/L
  d = 0.20 x 0.9 = 0.18 mg/L
- The t value for >120 d.f. at *p* = 0.05 is 1.96

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Mean Estimation - Example

For a 10% difference:

$$n = \frac{(1.96)^2\,(0.77)^2}{(0.09)^2} = 281$$

Because the t value for n=281 remains 1.96, additional steps are not necessary.

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Mean Estimation - Example

For a 20% difference:

$$n = \frac{(1.96)^2\,(0.77)^2}{(0.18)^2} = 71$$

Because the value of t at 70 d.f. is 1.99, a second iteration is necessary:

$$n = \frac{(1.99)^2\,(0.77)^2}{(0.18)^2} = 73$$

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Mean Estimation - Example

73 samples/yr → mean TP concentration ± 20% of the true mean,

281 samples/yr → mean TP concentration ± 10%

Mean Estimation

Can work backwards to evaluate proposed frequency – knowing n, solve for d:

- For monthly sampling:

$$12 = \frac{(1.78)^2 (0.77)^2}{(d)^2} \qquad d = 0.36 \rightarrow \pm 40\% \text{ of true mean}$$

- For quarterly sampling:

$$4 = \frac{(2.13)^2 (0.77)^2}{(d)^2} \qquad d = 0.56 \rightarrow \pm 62\% \text{ of true mean}$$

Minimum Detectable Change

- If the monitoring objective is to detect and document a change in water quality due to implementation, selected sampling frequency should be able to detect the magnitude of the anticipated change within the natural variability of the system being monitored.

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Minimum Detectable Change

Easy when the groups are very different, when random variability is small, and when the number of samples from each group is large.

Very difficult when the difference or change is very small, when natural variability is large, and when sample numbers are small

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Minimum Detectable Change

$$MDC = t_{(n_{pre}+n_{post}-2)}\sqrt{\frac{MSE_{pre}}{n_{pre}}+\frac{MSE_{post}}{n_{post}}}$$

Where:

t = the student’s t value with (n_{pre}+n_{post}-2) degrees of freedom (in this case selected at *p*=.05),

n = the number of samples taken in the pre- and post- groups, and

MSE = the mean square error in each period

MSE = σ^2/n

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Minimum Detectable Change

Example:

Based on historical monitoring data from the Erod River, annual mean TSS concentration is 36.9 mg/L, with a standard deviation of 2.65 mg/L.

Evaluate the minimum detectable change for weekly, monthly, and quarterly sampling before and after implementation of erosion control measures

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Minimum Detectable Change

Example:
For weekly sampling (n = 52), MSE = 0.135
The value of t for 102 d.f. at p = 0.05 is 1.662

$$MDC = 1.662 \sqrt{\frac{0.135}{52} + \frac{0.135}{52}}$$

$$= 0.119 = 12\%$$

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Minimum Detectable Change

Example:
For monthly sampling (n = 12), MSE = 0.585
The value of t for 22 d.f. at p = 0.05 is 1.717

$$MDC = 1.717 \sqrt{\frac{0.585}{12} + \frac{0.585}{12}}$$

$$= 0.536 = 54\%$$

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Minimum Detectable Change

Example:
For quarterly sampling (n = 4), MSE = 1.756
The value of t for 6 d.f. at p = 0.05 is 1.943

$$MDC = 1.943 \sqrt{\frac{1.756}{4} + \frac{1.756}{4}}$$

$$= 1.821 = 182\%$$

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Minimum Detectable Change

•If a reduction of 25% in mean annual TSS concentration is a goal of an implementation project, a weekly sampling schedule could document such a change with statistical confidence, but monthly sampling could not.

•A reduction of 54% or more in TSS concentration would need to occur to be detected by monthly sampling.

•Quarterly sampling for TSS would be ineffective for this project

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Minimum Detectable Change

MDC analysis can also be applied to designing a post-treatment sampling program if pre-treatment sampling has already been conducted.

However, if the pre-treatment sampling frequency was low, it will be difficult to compensate after the fact.

In the quarterly sampling example, even weekly sampling in the post-treatment period would improve the MDC only to 97%.

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Role of Cost

- Cost should affect but not dictate sampling frequency and duration
  - Consider dropping stations and variables to allow adequate frequency and duration
  - If cannot afford to do it right…don't do it at all

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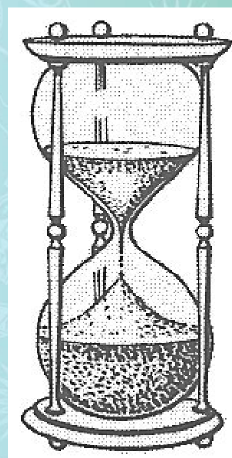
Sampling Duration - Lag time

An inherent characteristic of natural systems generally defined as the amount of time between an action and the response to that action



Lag time is the time elapsed between installation or adoption of land treatment and measurable improvement of water quality.

If lag time > monitoring period…..

may not show definitive water quality results

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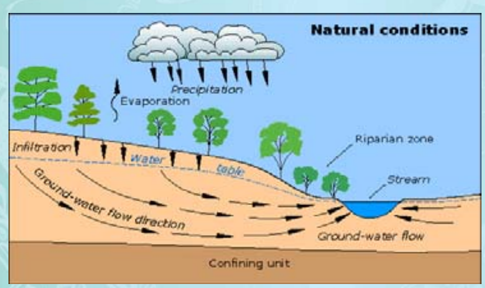
Time Required for Effect to be Delivered

- **Delivery route**
  - Direct or adjacent
  - Overland flow
  - Ground water



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Time Required for Effect to be Delivered

• **Path distance**

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Time Required for Effect to be Delivered

•**Path travel rate**

- Fast (ditches, tile outlets)
- Moderate (overland./subsurface flow in porous soils
- Slow (groundwater infiltration w/o macropores)
- Very slow (regional aquifer)

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Time Required for Effect to be Delivered

- **Precipitation patterns**

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